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13. ABSTRACT (Maximum 200 words) This study investigated temporal differences in body dimensions (height, weight, percent body fat (%BF)) of U.S. Army male soldiers by comparing 2004 and 1988 databases. Identified anthropometric somatotypes were subsequently incorporated in a thermal regulatory model to examine simulated individual differences in core temperature (Tcr) to heat stress (35° C/50% rh, ~550W work rate, rest for 30min and walk for 70 min). A significant increase in body weight (2.4kg) was observed between the 2004 and 1988 data (p < 0.05, after Bonferroni correction). However, changes in height and circumference measurements for %BF were insignificant, with the magnitude of the changes not exceeding inter-observer errors. Multivariate analyses demonstrated that anthropometric distributions did not differ between the two databases and identified five primary somatotypes: "tall-fat," "tall-lean," "average," "short-lean," and "short-fat." Within each database, anthropometric values differed among the somatotypes. However, simulated Tcr responses to heat stress in each somatotype were similar in the 2004 and 1988 populations. In conclusion, an increase in body weight was the primary change observed in the U.S. Army male soldiers. Temporal changes in somatotypes of soldiers over a 16 year period had minimal impact on simulated physiological response to heat stress using a thermal regulatory model.				
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ASSESSMENT OF MALE ANTHROPOMETRIC TRENDS AND THE EFFECTS ON THERMAL REGULATORY MODELS

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INTRODUCTION

Over the past 20 years, the trend towards excessive body weight and obesity among adults has become epidemic in the United States (2). To combat this issue, the U.S. Army established incremental age categories for weight-for-height requirements for Soldiers (4). If a Soldier's body weight exceeds the specified limits within his or her age category, body fat percentage (%BF) must be measured. Soldiers who exceed their %BF standard are enrolled in the Army Weight Control Program (3). Assessing the trends of body composition and dimensions in U.S. Army populations is important because body measurements affect Soldiers' health, fitness, performance, and safety in the work place (8). This study investigates temporal differences of body dimensions in U.S. Army male Soldiers, by comparing 2004 and 1988 anthropometric databases (1,5). In addition, the effects of the anthropometric changes on individual thermal physiological responses to a heat stress were evaluated by a thermal regulatory model (9).

METHODS

The height, weight, and %BF of male volunteers with self-reported race/ethnicity from the 2004 database ($n = 480$) were compared with those from the 1988 database ($n = 1773$) (1,5). Trained anthropometrists measured volunteers consistent with Army Regulation (3). Body fat was estimated from neck and abdominal circumference measurements using the U.S. Department of Defense (DOD) %BF equation (3). Anthropometric distributions in the two datasets were compared using analysis of variance and principal component analysis (PCA). PCA provides the best representations of multivariate data in simpler dimensions, by transforming linear orthogonal axes (eigenvectors) and maximizing variation (eigenvalues) of the data. The multivariate distribution using PCA was identified with two ellipses representing the majority 90% of the two populations. The influence of individual anthropometric variations on responses to heat stress predicted by a thermoregulatory model (9) were also addressed. The simulated heat stress challenges consisted of: non-acclimatized individuals, carrying a 12 kg load, wearing battle dress uniform (BDU) and body armor, having rested for 30 min, and walking at 3 mph for 70 min in 35°C/50%rh. The anthropometric effects on core temperatures (T_{cr}) were predicted.

RESULTS

The anthropometric characteristics of the male Soldiers in the 1988 and 2004 databases are summarized in Table 1. The acceptance range of measurement errors according to inter-observer error standards (6) is also included. On average, a 2.3 kg increase in weight was observed in the 2004 data. Small increases in height (0.6 cm), BMI (0.6 kg/m²) and neck circumference (0.4 cm), and slight decreases in BF (0.8%) and abdominal circumference (0.4 cm) were observed. Although these changes were small, analysis of variance indicated the differences in height, BMI, body surface, and neck circumference between the 1988 and 2004 populations were significant. However, the small differences between the two populations were within the acceptance range of measurement error magnitudes (7).

Table 1. Descriptive summary of male anthropometrics and tolerance values of inter-observer errors based on 1988 and 2004 populations

Anthropometric variablesDatabase	Inter-observer error range		
	1988	2004	
n	1773	480	
Age (yr)	29 (7)	28 (8)	N/A
Height (cm)	175.9 (6.6)	176.5 (7.3)*	1.1
Weight (kg)	79.3 (3.0)	81.6 (12.2)*	0.3
Body Mass Index	25.6 (3.0)	26.2 (3.6)*	N/A
Body fat (%)	18.5 (5.5)	17.7 (6)	N/A
Body surface (m ²)	1.95 (0.15)	1.98 (0.16)*	N/A
Neck circumference (cm)	38.1 (2.0)	38.5 (2.3)*	0.6
Abdominal circumference (cm)	87.6 (8.7)	87.2 (9.2)*	1.2

N/A: not available; anthropometric values: mean (standard deviation).

*statistical difference between the 1988 and 2004 database at $p < 0.05$ after Bonferroni correction (7 measurements)

Figure 1 presents a two-dimensional plot constructed from the PCA results, with two 90% ellipses representing the 1988 and 2004 populations. The results of the PCA indicate the similarity of the anthropometric distributions between the 1988 and 2004 populations. The first component (X axis) represents 61% of the total variation and corresponds to all positive loadings of variables indicating overall body size (Figure 1). The second component (Y axis) represents 34% of the total variation and corresponds with dichotomous loadings between height and %BF, and a low loading on weight. These loadings indicate the dichotomous somatic shapes, such as “tall-lean” vs. “short-fat.” The third component, corresponding to a somatotype, such as short football players (short with low fat yet heavy weight), was eliminated because it represented only 5% of the total variation. The labels in Figure 1 indicate the primary somatotypes. The anthropometric values converted from PC scores were also included. The somatotypes of these extreme individuals in both populations are defined as, “tall-fat (A),” “tall-lean (B),” “average (M),” “short-lean (C),” and short-fat (D).” For instance, B⁰⁴ in Figure 1 corresponds to “tall-thin” somatotype (Height: 191cm; Weight: 83kg; BF: 9%) from the 2004 population. Anthropometric values were subsequently applied to a thermal regulatory model for physiological comparisons.

Figure 2 shows T_{cr} comparisons between somatotypes in the 2004 population. At a T_{cr} level of 38.5°C, the probability for thermal injury is 25% (10). Based on the time for T_{cr} to reach 38.5°C, male Soldiers, depending upon their somatotype, can perform their tasks for up to 89 minutes in the simulated hot environment. “Short-lean” individuals, and to a lesser extent “tall-lean individuals”, were predicted to be more tolerant of heat stress and able to maintain lower T_{cr} at any given point in time. On the other hand, “fat” individuals, whether short or tall, were predicted to experience a greater heat strain. The “lean” individuals were able to work 20% longer than “fat” individuals. Similar T_{cr} responses were also observed in the 1988 database. Overall, within each somatotype, differences in physiological responses were minimal and insignificant between the 1988 and 2004 datasets.

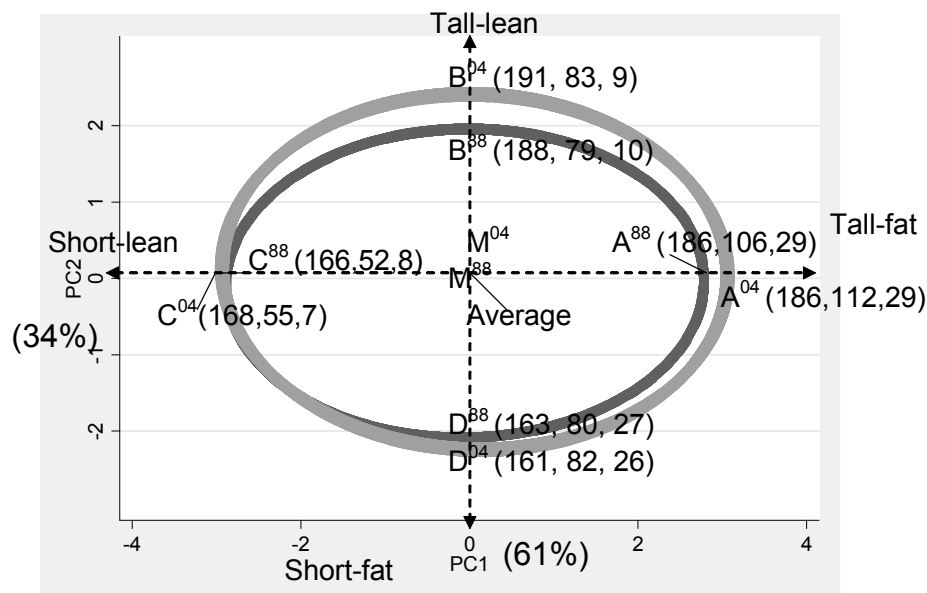


Figure 1. A two-dimensional plot for the 1988 and 2004 anthropometric males with 90% ellipses M⁰⁴: (Height: 177cm, Weight: 82kg, Body fat 18%); M⁸⁸: (176, 79, 19)

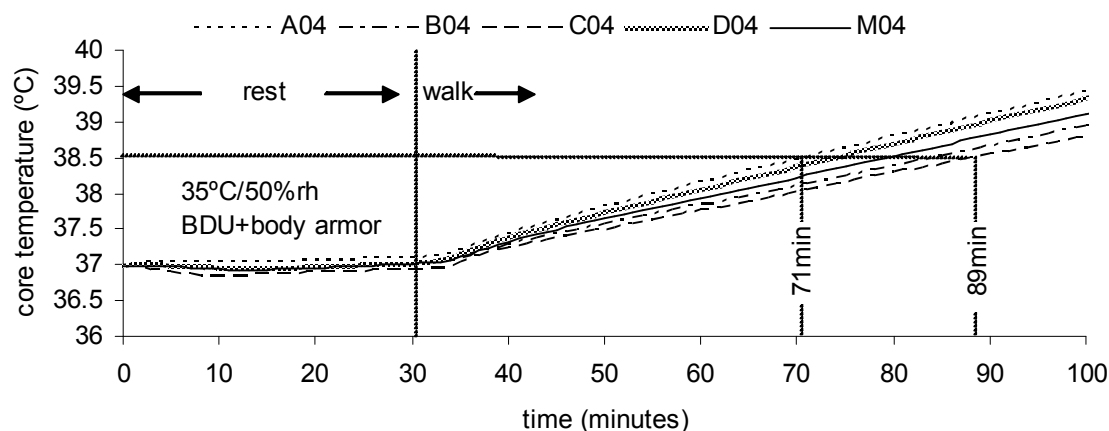


Figure 2. Anthropometric effects on core temperatures by somatotypes (2004 database). A⁰⁴: “tall-fat”, B⁰⁴: “tall-lean”, C⁰⁴: “short-lean”, D⁰⁴: “short-fat”, M⁰⁴: “average” somatotypes

DISCUSSION

This study showed secular trends in body measurements and composition among male U.S. Army Soldiers from 1988 to 2004, and evaluated the effects of these changes on simulated T_{cr} responses to heat stress. We found a significant increase in body weight in these two groups of U.S. Army males, even though most of them complied with weight control standards (1). However, the temporal changes in height, %BF and body circumferences were insignificant, with the magnitude of the changes not exceeding inter-observer errors. These results suggest that the relationship between BMI and body composition differ between military and non-military populations. That is, in non-military populations, an increase in BMI associated with increased body weight is generally thought to reflect an increased level of body fatness. However, a weight increase in the Army populations does not necessarily indicate a

concomitant increase in body fat since previous studies have suggested that increases in body weight can be primarily associated with increases in fat-free mass, rather than fat mass (4,8). Five identified somatotypes in multivariate anthropometric distributions showed different predicted heat tolerance levels. Yet, the change in each somatotype between 1988 and 2004 had a minimal affect on simulated T_{cr} response to heat stress. In this study, “small/lean” individuals, having low %BF and a higher body surface area per mass for dissipating heat, were predicted to maintain a lower T_{cr} for given exercise and environmental conditions. However, operational factors (e.g., environmental conditions, clothing, physical activity, load carriage) may impact the thermal strain experienced by individuals with different somatotypes in different ways.

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DISCLAIMER

The investigators have adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 32 CFR Part 219. The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or as reflecting the views of the Army or the Department of Defense. Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.